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V. *An Account of several Experiments made to examine the Nature of the Expansion and Contraction of Fluids by Heat and Cold, in order to ascertain the Divisions of the Thermometer, and to make that Instrument, in all places, without adjusting by a Standard.* By Mr. Edm. Halley, S. R. S.

Qualities, such as Heat and Cold, Moisture and Driness, and the like, are not otherwise to be estimated, but by their Effect on the *Quantity* of some body they act on, encreasing or lessening the Dimensions thereof; or else by the Motions they produce, both which subject them to Mensuration; but it is still a Question how to ascertain the proportional Heat or Cold, &c. that is between any two Climates or Seasons, so as to conclude the one, for Example, twice as hot or twice as cold as the other, tho' the Instruments now in use abundantly suffice to shew when the Temper of the Air is the same, and when it is Warmer or Cooler. The Reason hereof is, that we know not the Causes of the Expansion of *Fluids* by Heat, or of their Contraction by Cold, as arising from the Nature of their constituent parts, which are so far from being Objects of our Sense, that they even surpass our most refined Reasonings, and extort a Confession of our Ignorance after all our Endeavours. For the same degree of Heat does not proportionally expand all *Fluids*; some swelling with a gentle Warmth, and others not till they be considerably Hot; some boiling with a moderate Heat, and others not at all. Some capable of great Expansion, others encreasing very little; so that it may well be concluded that no one of them does encrease and diminish in the same

same proportion with the Heat, and consequently that the *Thermometers* graduated by equal Parts of the Expansion of any Fluid, are not sufficient Standards of Heat or Cold.

This will be more evident from the Experiments which I made some time since, with Water, Mercury, and Spirit of Wine, wherein the following Particulars were very remarkable.

I. I took a large Bolt-Head, holding about $3\frac{1}{2}$ L of Water, with a narrow Neck to make the Augment thereof more sensible; and having filled it with Water, and some few Inches up the Neck, I noted exactly to what Mark the Water came; then I immersed it into a Skillet of warm Water, and let it stand so long, till I concluded the warm Water had communicated its Temper to the Water included in the Bolt Head. And I found that tho' the Water were warm, much beyond the degree of the Summers Heat, and notwithstanding it was Winter; yet that gentle Heat had scarce any effect in dilating the Water, so that it scarce appeared to have ascended in the Neck of the Bolt-head. Then I took the Skillet and set it over the Fire, when it was observable that the Water as it grew hot did slowly ascend in the Neck, especially at first; but after it began to boil in the Skillet, the Expansion thereof became more visible, and it ascended apace till such time as it stopped again, the utmost Effort of Boiling Water being able to raise it no higher: Then having made a Mark at the utmost height whereto it had arisen, I took it out, and had the satisfaction to observe, that though it was not raised so high without a very strong boiling, yet it subsided very slowly, as retaining some time the space it had acquir'd from the Heat, even after the Heat was pass'd, and the Glass was so cool as to be touched without burning the Fingers. However the next morning I found it reduced to the first Mark, where it stood when at first put in, having

ving lost nothing sensible by Evaporation during the Experiment, which I attribute to the length of the Neck wherein the Vapors were condensed into Drops before they reached the Top. Then I examined how much Water would raise that in the Neck to the Mark where-to it had been encreased by boiling, and found it was a *twenty sixth part* of the bulk of the first Water, which upon repeated Experiment I found to be true ; but it was obvious that Water, encreasing so very little with all the degrees of Heat the Air receives from the Sun, was a very improper Fluid to make a *Thermometer* withal; and besides, any freezing Liquor is useless for this purpose in these Northern Climates.

II. I took a smaller Bolt-head with a proportional Cane or Neck, and filled it, after the same manner, with *Mercury*, and having boiled it as above, I observed that 125 Ounces of *Mercury* had encreased the space of 810 Grains, or a *Seventy fourth part* of its bulk when Cold. But it was very remarkable, that whereas a gentle Heat had scarce any effect on Water, here on the contrary, the *Mercury* did sensibly ascend at first, and had almost attained its greatest Expansion before the Water boiled in the Skillet. And after it boiled, though I let it stand very long over the Fire, I could not discern that the most vehement boiling had any effect on it, above what appeared when it first began to boil: The *Mercury* being taken out, as it cooled subsided, and in a few Hours returned to the Mark whereat it stood before it was put into the Water. This Fluid being so sensible of a gentle Warmth, and withal not subject to evaporate without a good degree of Fire, might most properly be applied to the Construction of *Thermometers* were its Expansion more considerable.

However small as it is, it is sufficient to disturb the precise nicety of the *Mercurial Barometers*, shewing the counterpoise of the Pressure of the Atmosphere by a Cylinder

linder of *Mercury* ; for if *Mercury* be more expanded, and consequently lighter in warm Weather than in cold, it will necessarily follow, that the same weight of Atmosphere will require a taller Cylinder in Summer, and a shorter in Winter to counterpoise it. And if the Extremity of Weather do but occasion an 150th part difference, as 'tis probable it doth, the effect thereof on a *Barometer* will be a tenth of an Inch above and below the Mean, or a Fifth in all.

III. I fill'd the smaller Bolt-head with Spirit of Wine, and having set it in the Skillet of Water over the Fire, I found that it ascended gradually as the Heat encreased, but slower at first, and faster after it was well warm. At length being arrived at a certain degree of Heat, it would fall a boiling with great Violence, emitting Bubbles, which coming into the Neck of the Bolt-head, would lift all the Incumbent Spirit, till they had made their way through. And these succeeding one another very fast, would often raise the Spirit to the top of the Neck, and spill it ; so that I found I could go no further with this Liquor, than to that degree of Heat which occasion'd this boiling, and which wanted very much of that of boiling Water, being almost tolerable to the Touch. It was however very remarkable how exactly this degree of Heat was determin'd by the expansion of the Spirit, for in the instant it reached a certain Mark on the Neck, it began to emit its Bubbles : and having been taken out a little to cool and subside, it would certainly and constantly fall a bubbling again, when upon a second Immersion, it was arrived at the aforesaid Mark : During this Experiment, it appeared both by the Dew on the Neck, and by the Scent in the Room, that tho' the Neck were about 30 Inches long, yet the Spirit did evaporate very fast for the smallness of the Surface of the Liquor. And I have often noted the like Evaporations condensed in

Dew within the Head of the ordinary seal'd *Thermometers*, in very hot Weather.

This degree of Heat which made Spirit of Wine begin to boil, being determined so nicely as I have said, made me conclude, that this might very properly be taken for the Limit of the Scale of Heat in a *Thermometer*; and the effect thereof in the expansion of any other Fluid being accurately noted, might be easily transferred to any sort of *Thermometer* whatsoever. Only it must be observed, that the Spirit of Wine used to this purpose be highly rectified or dephlegmed, for otherwise the differing Goodness of the Spirit will occasion it to boil sooner or later, and thereby pervert the designed Exactness. And by the way give me leave to hint, that the sooner or later boiling of Spirit or Spiritous Liquors may possibly be as good a Test of their Strength and Perfection as their Specific Gravity, or any other yet used.

The Spirit of Wine I made use of was possibly none of the best, but I observed that at the point of boiling it had encreased *a twelfth part* in bulk: Which great Dilatation makes it a Liquor sufficiently adapted to our purpose, were it not for the evaporation thereof; and for the difference in goodness of the Spirit; and for that in length of time it becomes as it were effete, and loses gradually a part of its expansive Power, as I have been informed by those who have long kept them.

All these Experiments were made in the Months of *February* and *March* about Four Years since, the Weather being reasonably cold, and not freezing; and since I have not had the opportunity to try the effect of extreme Cold in contracting these Liquors, which must be refer'd till some sharp Winter present us with a Season proper for these Trials.

IV. Several other Liquors may be examined after this manner, but these alledged may suffice to shew the differing Effects of Heat upon differing Fluids; and that
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this Power of dilating and contracting with Heat and Cold is as specifically in them as their Gravity, Refraction, &c. But in none is it comparably so conspicuous as in that rare Elastick Fluid the Air ; for by several Experiments that I have made, I find that the Heat of Summer does expand the ordinary Air about a *Thirtieth part* ; and that late Honourable Patron of Experimental Philosophy, Mr. *Boyle*, in his History of Cold, *Tit. 18. Parag. 8. pag. 475.* alledges his own Trials, proving that the force of the strongest Cold in *England* does not contract the Air above a *twentieth part* : So that the Sum of a twentieth and thirtieth part being a twelfth part, we may conclude that the same Air which is extream Cold occupies *twelve parts of space*, in very hot Summer Weather will require *thirteen* such Spaces ; which is as great an Expansion as that of Spirit of Wine when it begins to boil : For which reason, and for its being so very sensible of Warmth or Cold, and continuing to exert the same Elastick Power after never so long being included, in my Opinion it is much the most proper Fluid for the purpose of *Thermometers*.

Now the *Thermometers* hitherto in use are of Two sorts ; the one shewing the differing Temper of Heat and Cold by the Expansion of Spirit of Wine, the other by the Air ; but I cannot learn that any of them of either sort were ever made or adjusted, so as it might be concluded, what the Degrees or Divisions of the said Instruments did mean ; neither were they ever otherwise graduated, but by Standards kept by each particular Workman, without any agreement or reference to one another : So that whatsoever Observations any curious Person may make by his *Thermometer*, to signify the degree of Heat in the Air or other thing, (which is of constant Use in Philosophical Matters) cannot be understood, unless by those who have by them *Thermometers* of the same Make and Adjustment. Much less has the way been
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shewn how to make this Instrument without a Standard, or to make two of them to agree artificially without comparing them together.

I thought to have finished this Discourse with shewing a Method of constructing and regulating *Thermometers* to the best Advantage; but finding it necessary to make some Experiments with more Curiosity than I have yet done, especially upon the Airs Expansions. I crave leave, till one of the next Transactions, to inform my self more fully in the matter, being unwilling to leave to the Trial of others, what perhaps I have better opportunity to examine my self, especially in what is most difficult in this nice Affair: I shall only propose, that whereas the usual *Thermometers* with Spirit of Wine, do some of them begin their degrees from a Point, which is that whereat the Spirit stands when it is so cold as to freeze Oyl of Anniseeds; and others from the Point of beginning to freeze Water: I conceive these Points are not so justly determinable, but with a considerable latitude: And that the just beginning of the Scales of Heat and Cold should not be from such a Point as freezes any thing, but rather from Temperature, such as is in places deep under ground; where the Heat of the Summer, or Cold in Winter have (by the certain Experiment of the curious Mr. *Mariotte* in the *Grottoes* under the Observatory at *Paris*) been found to have no manner of effect. But of this more hereafter.